CHAPTER 20

STILLING BASINS

20-1. General. A stilling basin is a channel structure of mild slope, placed at the outlet of a spillway, chute or other high-velocity flow channel, the purpose of which is to dissipate some of the high kinetic energy of flow in a hydraulic jump. Stilling basins or other energy-dissipating devices are almost always necessary in such circumstances to prevent bed scour and undermining of the structure when the high velocity stream is discharged into the downstream channel. There are many types of these devices available such as hydraulic jump basins, roller buckets, flip buckets, impact energy dissipating devices and stilling wells. In unusual cases involving major structures, use of a special type of device should be considered. Three of the most commonly used energy dissipators, namely, a stilling well, the US Bureau of Reclamation (USBR), Type VI Basin, and the St. Anthony Falls (SAF) stilling basin will be reviewed in subsequent sections. The discussion that follows will be confined to energy dissipators used in conjunction with circular storm-drain-outlets. It is possible that energy dissipating devices may be necessary at the end of other types of outlets.

20-2. Stilling well.

a. Description. The stilling well consists of a vertical section of circular pipe affixed to the outlet end of a storm-drain outfall. Components of a typical stilling well are shown in figure 20-1. In order to be effective, the top of the well must be located at the elevation of the invert of a stable natural drainage basin or an artificial channel. The area adjacent to the top of the well, including the side slopes and outfall ditch, is usually protected by riprap or paving.

b. Hydraulics. Energy dissipation is accomplished by the expansion of flow that occurs in the well, the impact of the flow on the base and wall of the stilling well opposite the pipe outlet, and the change in momentum resulting from redirection of the flow. Important advantages of an energy dissipator of this type are that energy loss is accomplished without the necessity of maintaining a specified tailwater depth in the vicinity of the outlet and construction is both simpler and less expensive because the concrete formwork necessary for a conventional basin is eliminated.

c. Well depth. The stilling wells suggested were recommended from tests conducted on a number of model stilling wells. The recommended height of stilling wells above the invert of the incoming pipe is two times the diameter of the incoming pipe, D_o. The recommended depth of well below the invert of the incoming pipe, T is dependent on the slope of the incoming pipe and the diameter of the stilling well, D_w, and can

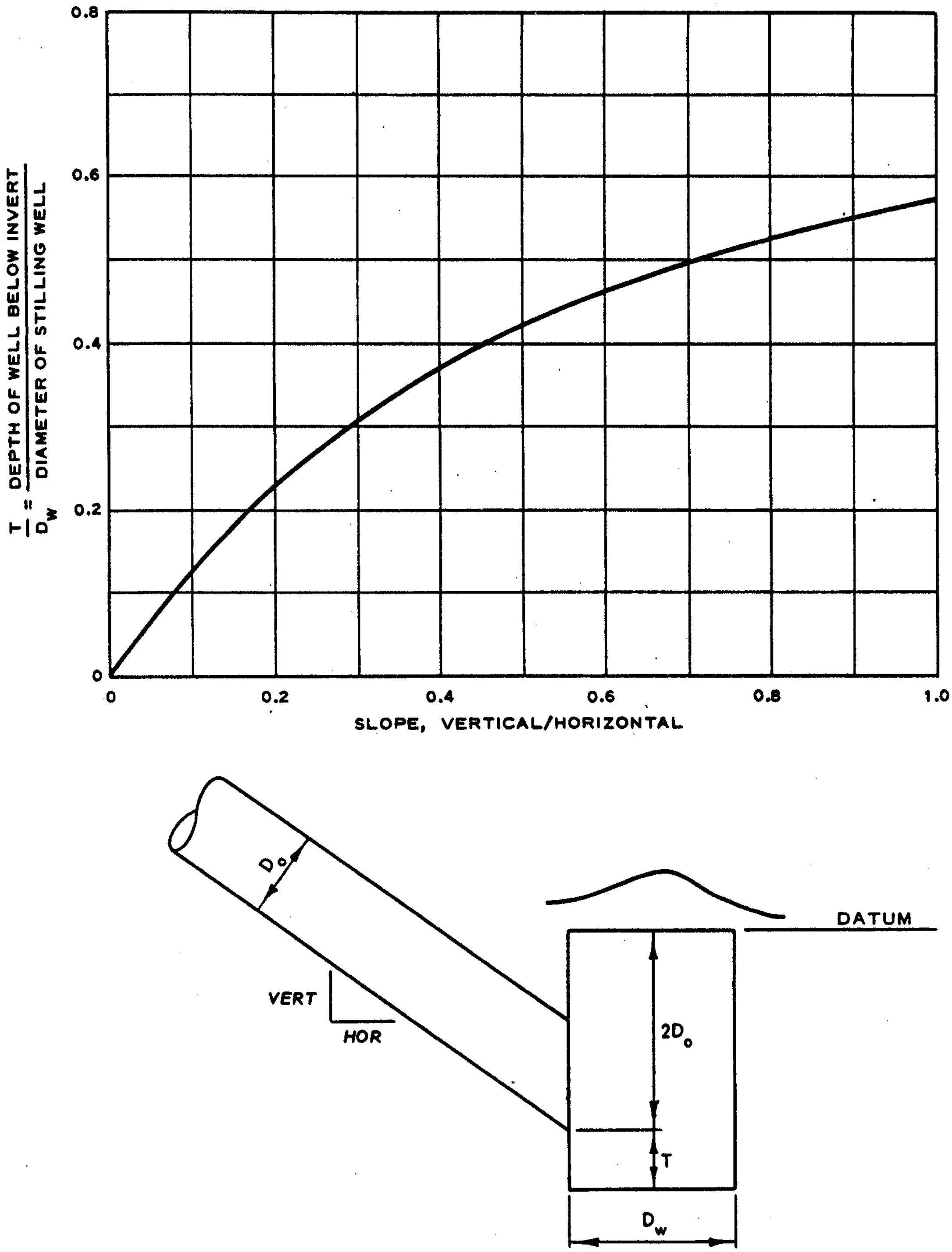

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FIGURE 20-1. STILLING WELL

be determined from the plot shown in figure 20-1. The model investigations indicated that satisfactory performance could be maintained for $Q/D_o^{5/2}$ ratios as large as 2.0, 3.5, 5.0, and 10.0, respectively, with stilling well diameters of one, two, three, and five times that of the incoming storm drain. The stated ratios were used to calculate the relations among actual storm-drain diameter, well diameter, and maximum discharge recommended for selection and design of stilling wells and shown in figure 20-2.

20-3. USBR Type VI basin.

a. Hydraulics. The USBR impact energy dissipator is an effective stilling device even with deficient tailwater. Dissipation is accomplished by the impact of the incoming jet on the vertical hanging baffle and by eddies formed by changing the direction of the jet after it strikes the baffle. Best hydraulic action is obtained when the tailwater elevation approaches, but does not exceed, a level half the height of the baffle. Excessive tailwater, on the other hand, will cause some flow to pass over the top of the baffle, which should be avoided, if possible. With velocities less than 2 fps, the incoming jet could possibly discharge underneath the hanging baffle. Thus, this basin is not recommended with velocities less than 2 fps. To prevent the possibility of cavitation or impact damage to the baffle, it is believed that an entrance velocity of 50 fps should not be exceeded with this device. The general arrangement of the Type VI basin and the dimensional requirements based on the width of the structure are shown in figure 20-3.

b. Model tests. The model used to test the limitations of the type VI basin was reported (by Beichley). The results of test on this particular model which had a width four times the diameter of the incoming pipe indicated that the limiting $Q/D_o^{5/2}$ value was 7.6. This value is slightly less than that recommended (by Beichley) in terms of the Froude number at the storm-drain outlet. The recommended relations between discharge, outlet diameters, and basin widths are shown in figure 20-4. With the discharge and size of the incoming pipe known, the required width of the basin can be determined from the design curves; other dimensions of the basin can be computed from the equations in figure 20-3.

20-4. SAF basin.

a. Description. The SAF stilling basin is a hydraulic jump type basin. All the dimensions of this basin are related in some way to the hydraulic jump. A reduction in the basin length from that of a natural hydraulic jump is achieved through the use of appurtenances consisting of chute blocks, floor blocks or baffle piers, and an end sill. General details of the SAF basin are shown in figure 20-5. Dimensions of the chute blocks and floor blocks may be modified slightly to

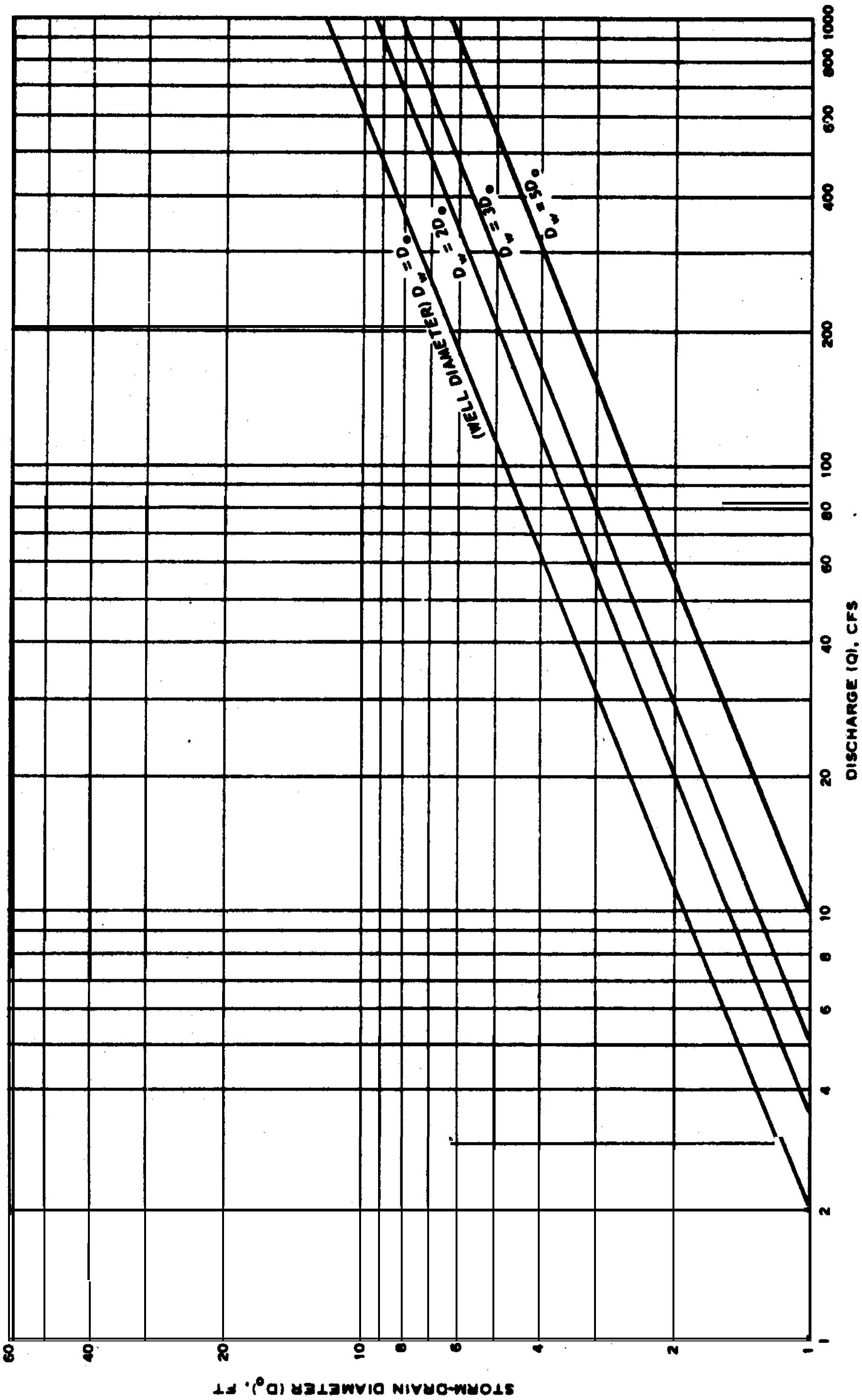

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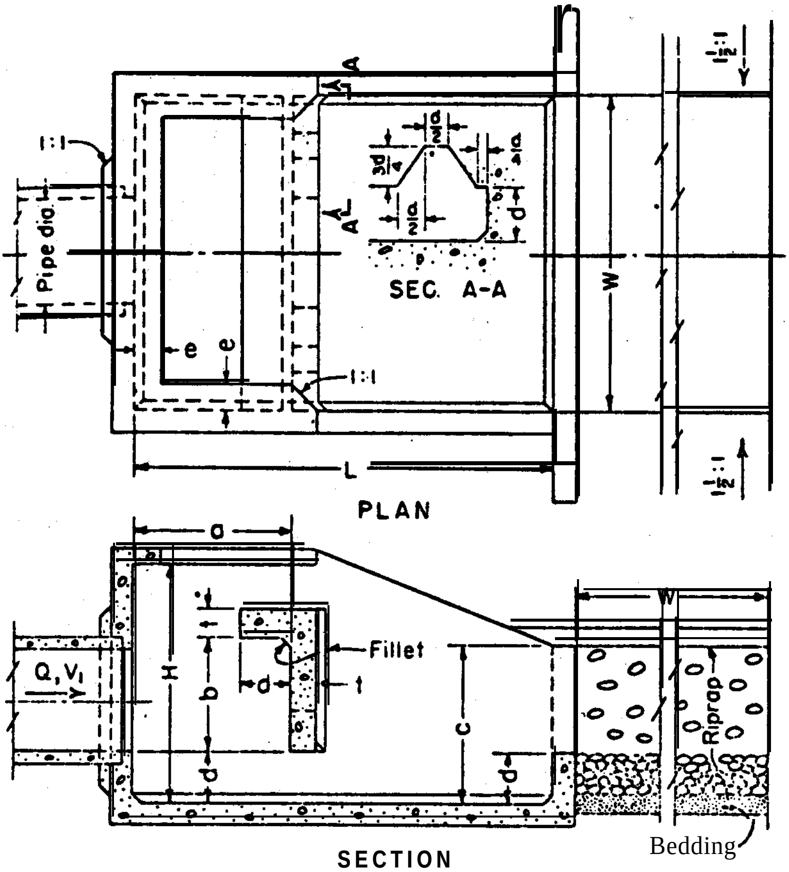
FIGURE 20-2. STORM-DRAIN DIAMETER VERSUS DISCHARGE STILLING WELL



STILLING BASIN DESIGN

H = 3/4 (W)
L = 4/3 (W)
a = 1/2 (W)
b = 3/8 (W)
c = 1/2 (W)
d = 1/6 (W)
e = 1/12 (W)
t = 1/12 (W), SUGGESTED MINIMUM
RIPRAP STONE SIZE DIAMETER = 1/20 (W)

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FIGURE 20-3 , USBR TYPE VI BASIN

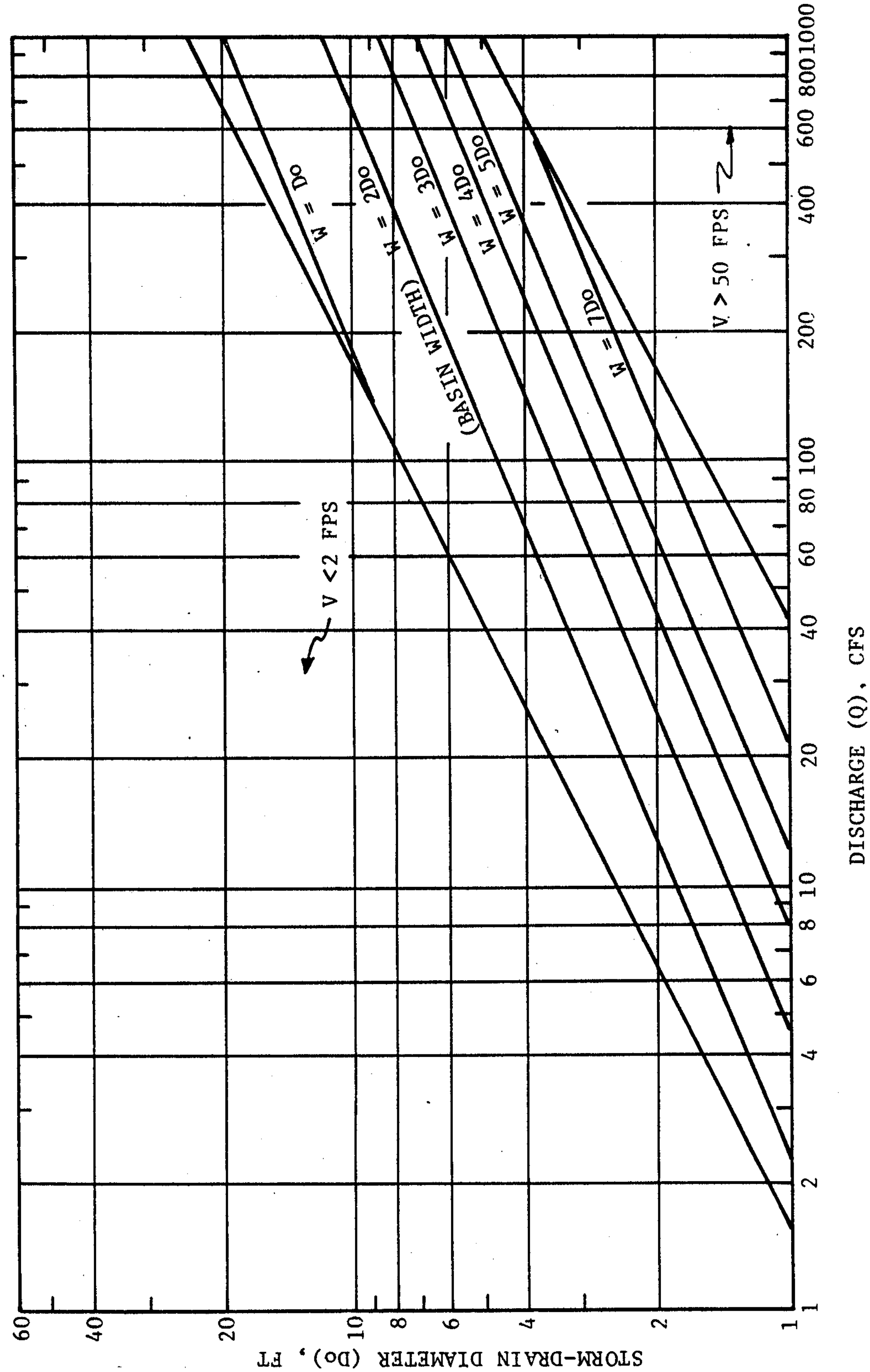

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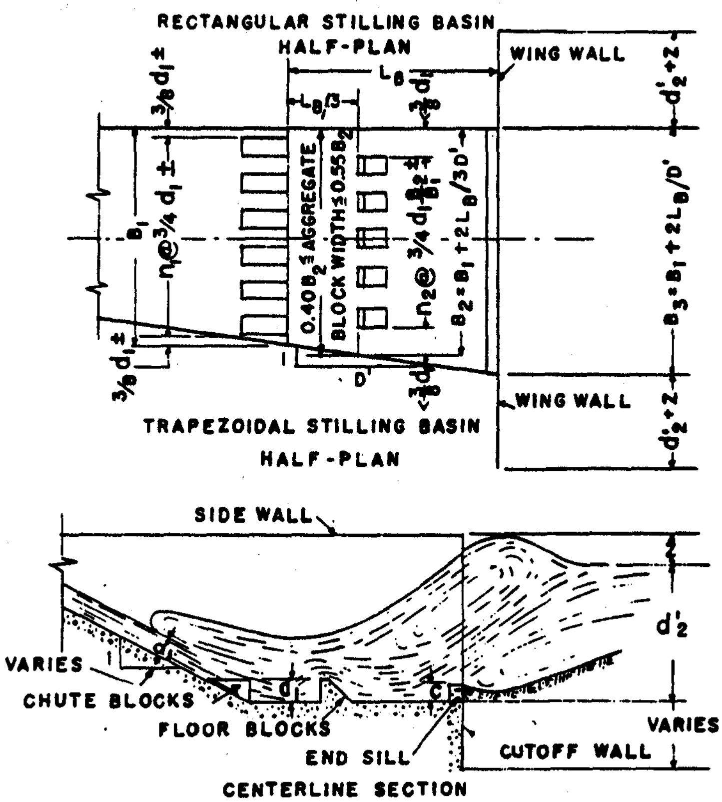
FIGURE 20-4. STORM-DRAIN DIAMETER VERSUS DISCHARGE USBR TYPE VI BASIN



DESIGN EQUATIONS

(1) $F = \frac{V_1^2}{g d_1}$ (2) $d_2 = \frac{d_1}{2}(-1 + \sqrt{8F + 1})$

(3a) F = 3 TO 30 $d'_2 = (1.10 - F/120)\, d_2$

(3b) F = 30 TO 120 $d'_2 = 0.85\, d_2$

(3c) F = 120 TO 300 $d'_2 = (1.00 - F/800)\, d_2$

(4) $L_B = \frac{4.5 d_2}{F^{0.38}}$ (5) $Z = \frac{d_2}{3}$ (6) $c = 0.07 d_2$

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FIGURE 20-5. PROPORTIONS OF SAF STILLING BASIN provide reasonable construction dimensions without materially affecting the efficiency of the structure.

b. Model tests. Several different models were constructed according to recommendations made from tests at the St. Anthony Falls Hydraulic Laboratory. Stilling basins one, two, and three times as wide as the outlet were tested with drops from the invert of the outlet to basin floor of one-half and two times the outlet diameter. The basins with widths of two and three times the outlet diameter were flared one on eight with respect to the center line of the structure. The size of the basin elements and the basin length were adjusted for the two apron elevations according to the depth of flow entering the basin. Comparisons of flow conditions for the various discharges with each basin were made with tailwater depths only sufficient to produce a hydraulic jump in the basin. Within the limits investigated, the drop from the invert of the outlet to the basin apron had little effect on the limiting $Q/D_o^{5/2}$ ratios. Maximum values of 3.5, 7.0, and 9.5 were indicated for $1D_o$, $2D_o$, and $3D_o$, $2D_o$, and $3D_o$ wide SAF stilling basins, respectively. These were used to determine the relations recommended for design and shown in figure 20-6.

20-5. Design summary.

a. Relationship of Froude number. The general design practice that has developed in recent years relative to highway culverts results in the conclusion that most of these structures convey discharges up to four or five times the diameter of the culvert raised to the five-halves power. The energy dissipator magnitude of this parameter will vary depending on the particular site or structure, but it is useful for classifying the relative design capacity of such structures. It is also related to the Froude number of flow commonly used in open channel hydraulics. For example, the Froude number of full pipe flow at the outlet of a circular pipe is unity for a $Q/D_o^{5/2}$ ration of 4.5

b. Widths versus maximum discharge. The range of applicability of maximum discharge capacity for various widths of the three commonly used energy dissipators relative to the diameter of the incoming culvert or storm-drain outlet, D_o is summarized in table 20-1. Based on these values of the relative maximum discharge capacity for comparable relative widths of the three energy dissipators, the stilling well is particularly suited to the lower range of discharges, the USBR Type VI basin to the intermediate range of discharges, and the SAF stilling basin to the higher range of discharges. However, all three of the energy dissipators are applicable for general drainage and erosion control practice. Comparative cost analyses will indicate which of the devices is the most economical energy dissipator for a given installation.

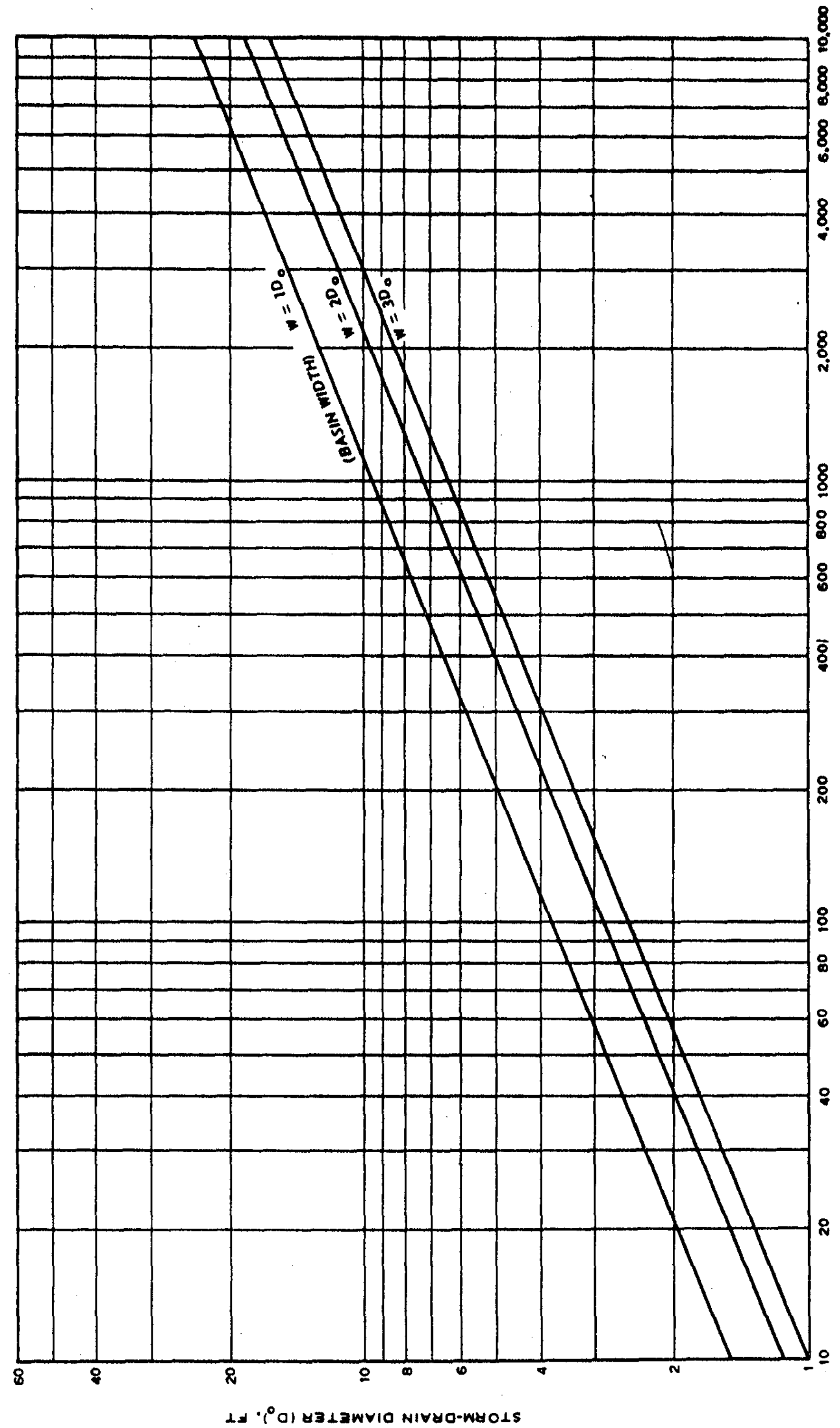

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FIGURE 20-6. STORM-DRAIN DIAMETER VERSUS DISCHARGE SAF STILLING BASIN

Table 20-1. Maximum Discharge Recommended for Various Types and Sizes of Energy Dissipators

Relative width and type of energy dissipator	Maximum $Q/D_o^{5/2}$
Stilling Well	
1 D_o diameter	2.0
2 D_o diameter	3.5
3 D_o diameter	5.0
5 D_o diameter	10.0
USBR Type VI Basin	
1 D_o wide	0.6
2 D_o wide	2.2
3 D_o wide	4.5
4 D_o wide	7.6
5 D_o wide	11.5
7 D_o wide	21.0
SAF Stilling Basin	
1 D_o wide	3.5
2 D_o wide	7.0
3 D_o wide	9.5

20-6. Comparison of various stilling basins. Using the given design curves for the three energy dissipators, the designer can determine the applicability and necessary dimensions of each type of energy dissipator. In some cases, more than one type of dissipator may be applicable and in such cases local terrain, tailwater conditions, and cost analyses will determine the most practical energy dissipator for protecting the outlet. For example, with a 60 inch diameter culvert and a design discharge of 290 cfs, either a 10-foot wide ($2D_o$) SAF stilling basin, or a 20-foot wide ($4D_o$) USBR Type VI basin, or a 20-foot diameter ($4D_o$) stilling well could be used. With a 48-inch diameter culvert and a design discharge of 110 cfs, a 4-foot wide ($1D_o$) SAF stilling basin or an 8-foot diameter ($2D_o$) stilling well or a 10-foot wide ($2.5D_o$) USBR Type VI basin could be used.

20-7. Design problem.

a. Use of SAF stilling basin design chart. The use of the SAF stilling basin chart (fig 20-7) is illustrated by the following problem. It will demonstrate that the dimensions of the chute blocks and floor blocks may be modified without materially affecting the efficiency of the structure.

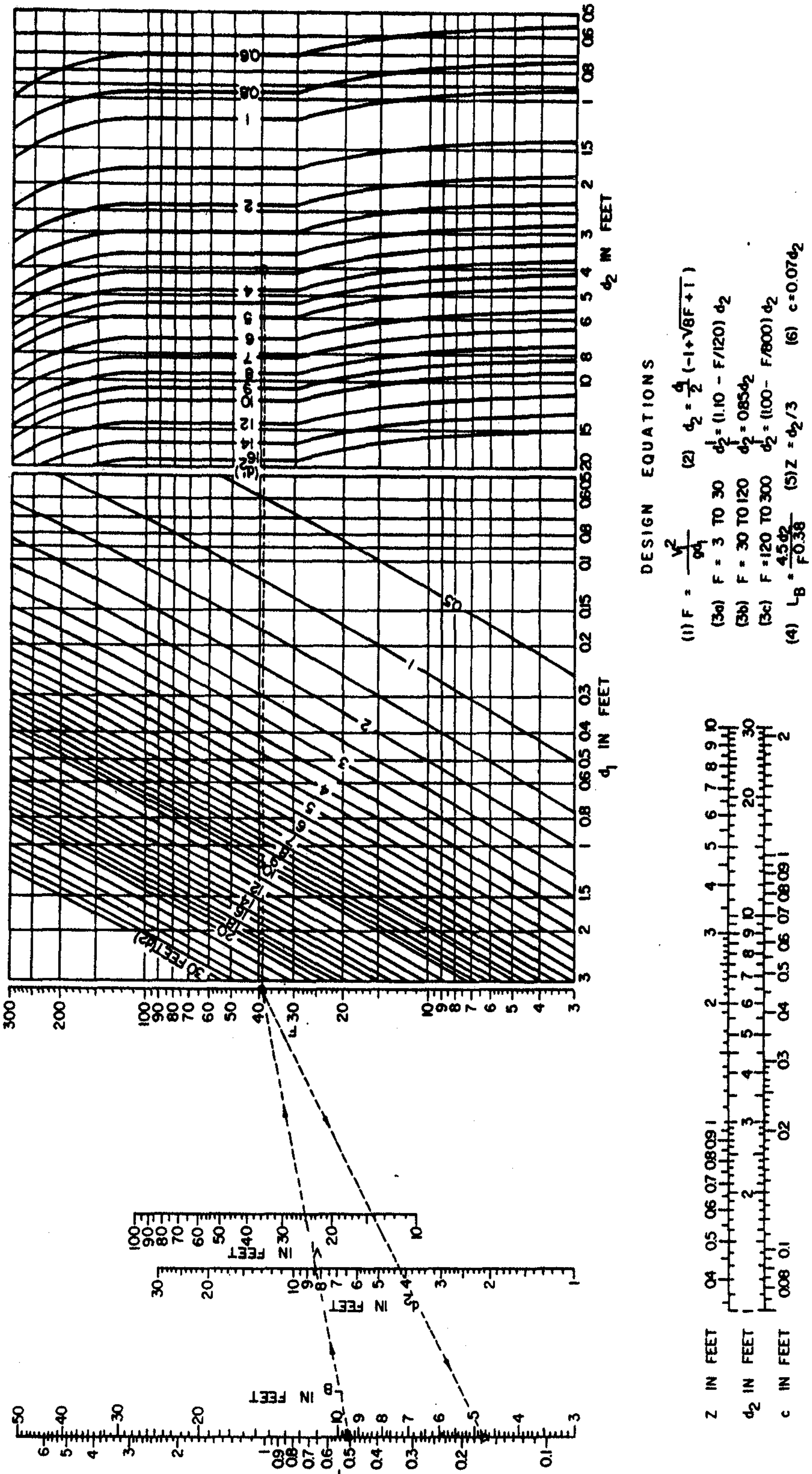

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FIGURE 20-7. DESIGN CHART FOR SAF STILLING BASIN

b. Design approach. The indicated design is for a rectangular stilling basin to be constructed at the outlet of a 4-foot-wide rectangular chute. The depth and velocity of the flow at the end of the chute are 0.5 foot and 25 fps, respectively, and the depth of flow in the outlet channel is 2 feet for the design discharge of 50 cfs.

20-8. Solution.

a. Principal dimensions. Reading the principal dimensions from the design chart it is found that d_2 = 4.2 feet, d_2' = 3.5 feet, L_B = 4.7 feet, Z = 1.4 feet, and c = 0.294 foot. In order to simplify construction, use L_B = 4.75 feet and c = 6 inches. (The height of end sill will be a minimum of 6 inches.) The height of the sidewall is d_2 + Z = 4.90 feet (use 5 feet) which places the top of the wall 1.5 feet above the tailwater elevation.

b. Alternate arrangements. Several arrangements of the 6-inch-high chute and floor blocks are possible, the floor blocks being placed one-third of the height of the sidewall or 1.67 feet downstream from the upper end of the basin. The width of the chute and floor blocks and the spaces between can be made 0.5 x 3/4 = 0.375 foot, or 4.5 inches. This gives 48/4.5 = 10+ spaces across the stilling basin. Locate 3.75-inch-wide chute blocks at either side of the flume and space remaining 4.5-inch-wide blocks on 9-inch centers across the chute.

c. Configuration of floor blocks. Floor blocks can be located downstream from spaces between chute blocks except that a floor block cannot be placed adjacent to sidewalls. This will result in 5 floor blocks or 5 x 4.5 x 100/48 = 47 percent of the width of the basin occupied by floor blocks. Considerable flexibility is permitted in designing chute and floor blocks, and a satisfactory arrangement can be developed using a block width of 6 inches with a chute block placed adjacent to the sidewalls.

d. Wingwalls. A wingwall will be provided with a height equal to that of the sidewall and a length determined by the side slopes of the outfall channel. A cutoff wall having a depth of 2 feet or more will be used. The outfall channel will be riprapped for a distance of at least L_B = 5 feet downstream from the stilling basin.